amended and both the base claim and the matter added to that claim by amendment are underlined, then it is impossible from the face of the document to determine what matter has been added. Furthermore, if material being deleted (shown in brackets) was previously submitted in a new claim and thus must be underlined throughout prosecution, then the deleted material is underlined leading to a designation of text with conflicting editorial designations (underlined material within brackets).

In the Response mailed December 23, 2002, Applicant submitted separate sheets showing changes to claims 24, 28, 30 and 35. Submitted herewith are two modified versions of that same document. In the first version, the entire claim language is underlined, except for language in brackets. In the second version, the entire claim language is underlined, including language in brackets. Note that the text of claims 39 and 40, added by the December 23, 2002, Amendment (and underlined in that Amendment) is provided and underlined, as required by paragraphs (b) and (d), in both versions.

Note also that while Applicant is cautioned in the present Action to include the parenthetical expressions "amended," "twice amended," etc., behind the claim number, in both the December 23, 2002, Amendment and the Supplemental Paper Amending Reissue Application sent that same day, the requisite parenthetical expressions appear to be appropriately supplied. They are assuredly included in the first and second versions of amendments to claims 24, 28, 30 and 25 enclosed herewith.

ITEM 2. In Item 2, the Examiner refers to the instant amendment as apparently distinguished from the amendment filed December 30, 2002 (the Amendment mailed by the undersigned on December 23, 2002) in Item 1. It is not clear to what the "instant amendment" refers. Is it the December 23, 2002, Amendment? Is it the Response to Advisory Action mailed January 30, 2003? If it is the latter, which it apparently is, there were no changes made to the claims in that Response. Only Remarks were presented. Thus, the provisions of paragraph (c) should not apply, i.e., there was not "an amendment to the claims pursuant to paragraph (b) of this section."

If, however, it was the December 23, 2002, Amendment, a separate page complying with paragraph (c) was submitted at that time. A

duplicate copy of that page is submitted herewith. Note that paragraph (c) only requires an explanation of support for claims that were changed. For sake of completeness and to avert another Advisory Action, an additional separate page is provided herewith that indicates support in the disclosure (the original patent) for all claims added to or modified in the reissue application as of the date of this submission.

Also submitted herewith are supplemental pages showing all claim amendments in the reissue application made prior to the December 23, 2002, Amendment. They are provided in a first version where the added claims are not underlined to show additions and a second version where all the remaining text of the added claims is underlined.

ITEM 3. The objected to pages (4,5,7,8,10,13,14,16,17 and 18) are resubmitted herewith with appropriate margins.

In view of the foregoing Amendments and these Remarks, Applicant submits that claims 1-23 and 24-40 are in condition for allowance and early notification of same is respectfully requested. Should the Examiner believe that a telephone conference would help further the prosecution of this case, the Examiner is requested to contact the undersigned at the listed telephone number.

The Assistant Commissioner is hereby authorized to charge underpayment of any fees (including any filing fees under 37 C.F.R. §1.16 for additional claims and any patent application processing fees under 37 C.F.R. §1.17 including any fee for extension of time) associated with this communication or credit any overpayment to Deposit Account No. 01-0272. A duplicate copy of this authorization is enclosed.

Respectfully Submitted
on behalf of Applicant,

Date: 3-26-03

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Ver. 1

24 (twice amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column [2-D] array, where M and N are positive integers and at least one of M and N is greater than one;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each control signal having a frequency and a phase component; and

wherein [said] each transducer [elements and said control circuit are] element is configured to function as an active device so as to achieve a combining at each transducer element of the frequency and phase components of the row and column control signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array.

28 (amended). The apparatus of claim 27, wherein [said coded signal is a chirp] M equals one.

30 (twice amended). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each row and column control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a combining at each transducer element of the frequency and [a] phase components of the row and column control signals for that transducer element with a resultant electrical receive signal, corresponding to an acoustic signal incident on that transducer element, in such a manner as to modify the frequency and phase of the transducer element's electrical receive signal so as to achieve the coherent

combination of the modified electrical receive signals from all of said plurality of transducer elements; and

a filter that filters spurious frequencies output from the transducer elements;

wherein said transducer elements, control circuit and filter are configured [to coherently combine the electrical receive signal of each of said transducer elements and] to achieve focused acoustic signal reception at a given distance and direction from said array.

35 (amended). The apparatus of claim [33] 29, wherein [said matched filter includes a conjugate of a chirp signal] M equals one.

New claims submitted December 23, 2003:

39 (new). The apparatus of claim 38, wherein M equals one.

40 (new). The apparatus of claim 24, wherein each transducer element includes non-linear electro-acoustic material.

Ver. 2

24 (twice amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column [2-D] array, where M and N are positive integers and at least one of M and N is greater than one;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each control signal having a frequency and a phase component; and

wherein [said] each transducer [elements and said control circuit are] element is configured to function as an active device so as to achieve a combining at each transducer element of the frequency and phase components of the row and column control signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array.

28 (amended). The apparatus of claim 27, wherein [said coded signal is a chirp] M equals one.

30 (twice amended). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each row and column control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a combining at each transducer element of the frequency and [a] phase components of the row and column control signals for that transducer element with a resultant electrical receive signal, corresponding to an acoustic signal incident on that transducer element, in such a manner as to modify the frequency and phase of the transducer element's electrical receive signal so as to achieve the coherent

combination of the modified electrical receive signals from all of said plurality of transducer elements; and

a filter that filters spurious frequencies output from the transducer elements;

wherein said transducer elements, control circuit and filter are configured [to coherently combine the electrical receive signal of each of said transducer elements and] to achieve focused acoustic signal reception at a given distance and direction from said array.

35 (amended). The apparatus of claim [33] 29, wherein [said matched filter includes a conjugate of a chirp signal] M equals one.

New claims submitted December 23, 2003:

39 (new). The apparatus of claim 38, wherein M equals one.

40 (new). The apparatus of claim 24, wherein each transducer element includes non-linear electro-acoustic material.

Duplicate of
Dec. 23, 2002
Submission

STATUS OF CLAIMS AND SUPPORT FOR CLAIM CHANGES UNDER 37 C.F.R. §173(c)

Claims	Status	Support
1-23	pending	Not substantively amended, support in original specification.
24	pending	Claim 16, etc.
25	"	Not substantively amended.
26	"	Not substantively amended.
27	"	Not substantively amended.
28	"	Fig. 12, etc.
29	"	Allowed.
30	"	Claim 1, Fig. 2, etc.
31	"	Not substantively amended.
32	"	Not substantively amended.
33	"	Not substantively amended.
34	"	Not substantively amended.
35	"	Fig. 12, etc.
36	"	Figs. 1-3, etc.
37	"	Not substantively amended.
38	"	Allowed.
39	"	Fig. 12, etc.
40	"	Claims 11,19, etc.

SEPARATE PAGE UNDER 37 C.F.R. §173(c)GIVING STATUS OF AND SUPPORT FOR ALL CLAIMS

Status as of March 26, 2003.

Claims	Status	Support
1-23(in patent)	pending	Not substantively amended, support in original patent.
24	pending	Claim 16, etc.
25	"	Claims 19, 21, etc.
26	"	Claim 12, Fig. 2, etc.
27	"	Claim 1, Figs. 4 and 9, etc.
28	"	Fig. 12, etc.
29	"	Claim 16, etc.
30	"	Claim 1, Fig. 2, etc.
31	"	Col. 11, line 1+, etc.
32	"	Claims 19, 21, etc.
33	"	Fig. 3, etc.
34	"	Col. 7, lines 14-24, etc.
35	"	Fig. 12, etc.
36	"	Figs. 1-3, etc.
37	"	Claim 12, Fig. 2, etc.
38	"	Claim 12, etc.
39	"	Fig. 12, etc.
40	"	Claims 11,19, etc.

Ver. 1

SUPPLEMENTAL PAPER CORRECTLY AMENDING REISSUE APPLICATION

PRIOR AMENDMENTS to Claims Under §1.173(b)(2)

Note that previous claim amendments were submitted on 6/5/01 and 7/19/02. The below text includes these claim amendments and indicates their date of submission.

6/5/01

2 (amended). The apparatus of claim 1, wherein said coded signal is a chirp.

6/5/01

Claim 12, line 1, after "comprising:" please begin a new paragraph. Note that the requested carriage return and indentation are non-visible characters. Thus, Applicant is unsure of how to make this amendment pursuant to §1.173(b)(2) and (d).

6/5/01

13 (amended). The apparatus of claim 12, wherein said array has a plurality of rows and a plurality of columns each having one of said plurality of control channels associated therewith;

said control signal generating means further including means for generating row and column control signal components; and

wherein each transducer element is uniquely and simultaneously controlled by a combination of the row and column control signal components for that transducer element.

6/5/01

23 (amended). An acoustic imaging apparatus, comprising:

control logic;

a plurality of transducer elements arranged in an array, each coupled to said control logic and capable of transmitting an acoustic signal representative of an electrical transmit control signal propagated from said control logic and generating an

electrical receive signal representative of an incident acoustic signal;

means within said control logic for generating an electrical transmit control signal for each transducer element that contains a frequency based coded signal and [cause] causing each transducer to emit an acoustic signal representative of said coded signal;

means for modifying the frequency and [chase] phase of an electrical receive signal of each transducer element for coherently combining reflected coded signals within the electrical receive signals thereof;

means coupled to said modifying means for decoding the combined reflected coded signals to achieve a time delay base on that coded signal; and

means coupled to said decoding means for generating image data from an output signal therefrom.

7/19/02

24 (amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column 2-D array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a [mixing] combining at each transducer element of the frequency and phase components of the row and column control [signal] signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array.

6/5/01

26 (amended). The apparatus of claim 24, wherein said control circuit includes a control channel for each of said M rows and a control channel for each of said N columns, and wherein the

number of control channels is fewer than the number [to] of transducer elements.

7/19/02

29 (amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column [1-D] array, where M and N are positive integers and at least one of M and N is greater than one; [and]

M row control lines, each coupled to the transducer elements in one of said M rows;

N column control lines, each coupled to the transducer elements in one of said N columns;

control circuit for propagating row and column control signals for each of said M rows and said N columns, a control signal for each transducer element being a combination of one of said row control signals and one of said column control signals;

a plurality of active devices, each coupled to one of said transducer elements for combining the row control signal and the column control signal of that transducer element;

wherein said transducer elements [and said], control circuit and active devices are configured so as to achieve a [mixing] combining at each transducer element of the row and column control [signal] signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array; and

wherein each of said electro-acoustic transducer elements is configured within said apparatus to function in a non-linear manner in operation.

7/19/02

30 (amended). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each row and column control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a [mixing] combining at each transducer element of the frequency and a phase components of the row and column control [signal] signals for that transducer element with a resultant electrical receive signal corresponding to an acoustic signal incident on that transducer element; and

a filter that filters spurious frequencies output from the transducer elements;

wherein [the row and column control signals and said filter] said transducer elements, control circuit and filter are configured to coherently combine the electrical receive signal of each of said transducer elements and to achieve focused acoustic signal reception at a given distance and direction from said array.

6/5/01

33 (amended). The apparatus of claim 30, wherein said filter [is] includes a matched filter.

6/5/01

36 (amended). The apparatus of claim 30, wherein the transducer elements and the control circuit are configured such that the row and column control signals for each transducer element [contains a] contain an appropriate frequency and phase shift that, when combined with the electric signal corresponding to an incident acoustic signal at that transducer element, modifies the received electric signal in such a manner as to permit the coherent combination of the modified received electric [signal] signals from all of said plurality of transducer elements.

7/19/02

36 (amended). The apparatus of claim 30, [wherein the transducer elements and the control circuit are configured such that the row and column control signals for each transducer element contain an appropriate frequency and phase shift that, when combined with the electric signal corresponding to an incident acoustic signal at that transducer element, modifies the received electric signal in such a manner as to permit the coherent combination of the modified received electric signals from all of said plurality of transducer elements] further comprising a circuit that generates image data from the coherent combination of transducer element receive signals.

6/5/01

37 (amended). The apparatus of claim 30, wherein said control circuit includes a control channel for each of said M rows and a control channel for each of said N columns, and wherein the number of control channels is fewer than the number [to] of transducer elements.

Please add the following new claim:

7/19/02

38 (new). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements each capable of generating an electrical receive signal in response to an incident acoustic wave and arranged in an M row by N column array, where M and N are positive integers and at least one of M and N is greater than one;

control circuit for propagating row and column control signals for each of said M rows and said N columns, the control signal for each transducer element being a combination of the row and column control signals for that transducer element;

wherein said row and column control signals are configured, for each transducer element, such that when combined with the

electrical receive signal of that transducer element the electrical receive signal is modified in such a manner as to permit the simultaneous processing of the modified electrical receive signals from said plurality of transducer elements;

a first circuit that combines the modified electrical receive signals of each of said transducer elements to form an array output signal; and

a second circuit coupled to said first circuit that generates image data from said array output signal.

ver. 2

SUPPLEMENTAL PAPER CORRECTLY AMENDING REISSUE APPLICATION

PRIOR AMENDMENTS to Claims Under §1.173(b)(2)

Note that previous claim amendments were submitted on 6/5/01 and 7/19/02. The below text includes these claim amendments and indicates their date of submission.

6/5/01

2 (amended). The apparatus of claim 1, wherein said coded signal is a chirp.

6/5/01

Claim 12, line 1, after "comprising:" please begin a new paragraph. Note that the requested carriage return and indentation are non-visible characters. Thus, Applicant is unsure of how to make this amendment pursuant to §1.173(b)(2) and (d).

6/5/01

13 (amended). The apparatus of claim 12, wherein said array has a plurality of rows and a plurality of columns each having one of said plurality of control channels associated therewith;

said control signal generating means further including means for generating row and column control signal components; and

wherein each transducer element is uniquely and simultaneously controlled by a combination of the row and column control signal components for that transducer element.

6/5/01

23 (amended). An acoustic imaging apparatus, comprising:

control logic;

a plurality of transducer elements arranged in an array, each coupled to said control logic and capable of transmitting an acoustic signal representative of an electrical transmit control signal propagated from said control logic and generating an

electrical receive signal representative of an incident acoustic signal;

means within said control logic for generating an electrical transmit control signal for each transducer element that contains a frequency based coded signal and [cause] causing each transducer to emit an acoustic signal representative of said coded signal;

means for modifying the frequency and [chase] phase of an electrical receive signal of each transducer element for coherently combining reflected coded signals within the electrical receive signals thereof;

means coupled to said modifying means for decoding the combined reflected coded signals to achieve a time delay base on that coded signal; and

means coupled to said decoding means for generating image data from an output signal therefrom.

7/19/02

24 (amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column 2-D array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a [mixing] combining at each transducer element of the frequency and phase components of the row and column control [signal] signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array.

6/5/01

26 (amended). The apparatus of claim 24, wherein said control circuit includes a control channel for each of said M rows and a control channel for each of said N columns, and wherein the

number of control channels is fewer than the number [to] of transducer elements.

7/19/02

29 (amended). An acoustic energy transmitting apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column [1-D] array, where M and N are positive integers and at least one of M and N is greater than one; [and]

M row control lines, each coupled to the transducer elements in one of said M rows;

N column control lines, each coupled to the transducer elements in one of said N columns;

control circuit for propagating row and column control signals for each of said M rows and said N columns, a control signal for each transducer element being a combination of one of said row control signals and one of said column control signals;

a plurality of active devices, each coupled to one of said transducer elements for combining the row control signal and the column control signal of that transducer element;

wherein said transducer elements [and said], control circuit and active devices are configured so as to achieve a [mixing] combining at each transducer element of the row and column control [signal] signals for that transducer element in such a manner as to provide a focused acoustic signal at a given focal distance and direction from said array; and

wherein each of said electro-acoustic transducer elements is configured within said apparatus to function in a non-linear manner in operation.

7/19/02

30 (amended). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements arranged in an M row by N column array;

control circuit for propagating row and column control signals for each of said M rows and said N columns, each row and column control signal having a frequency and a phase component; and

wherein said transducer elements and said control circuit are configured so as to achieve a [mixing] combining at each transducer element of the frequency and a phase components of the row and column control [signal] signals for that transducer element with a resultant electrical receive signal corresponding to an acoustic signal incident on that transducer element; and

a filter that filters spurious frequencies output from the transducer elements;

wherein [the row and column control signals and said filter] said transducer elements, control circuit and filter are configured to coherently combine the electrical receive signal of each of said transducer elements and to achieve focused acoustic signal reception at a given distance and direction from said array.

6/5/01

33 (amended). The apparatus of claim 30, wherein said filter [is] includes a matched filter.

6/5/01

36 (amended). The apparatus of claim 30, wherein the transducer elements and the control circuit are configured such that the row and column control signals for each transducer element [contains a] contain an appropriate frequency and phase shift that, when combined with the electric signal corresponding to an incident acoustic signal at that transducer element, modifies the received electric signal in such a manner as to permit the coherent combination of the modified received electric [signal] signals from all of said plurality of transducer elements.

7/19/02

36 (amended). The apparatus of claim 30, [wherein the transducer elements and the control circuit are configured such that the row and column control signals for each transducer element contain an appropriate frequency and phase shift that, when combined with the electric signal corresponding to an incident acoustic signal at that transducer element, modifies the received electric signal in such a manner as to permit the coherent combination of the modified received electric signals from all of said plurality of transducer elements] further comprising a circuit that generates image data from the coherent combination of transducer element receive signals.

6/5/01

37 (amended). The apparatus of claim 30, wherein said control circuit includes a control channel for each of said M rows and a control channel for each of said N columns, and wherein the number of control channels is fewer than the number [to] of transducer elements.

Please add the following new claim:

7/19/02

38 (new). An acoustic energy receiving apparatus, comprising:

a plurality of electro-acoustic transducer elements each capable of generating an electrical receive signal in response to an incident acoustic wave and arranged in an M row by N column array, where M and N are positive integers and at least one of M and N is greater than one;

control circuit for propagating row and column control signals for each of said M rows and said N columns, the control signal for each transducer element being a combination of the row and column control signals for that transducer element;

wherein said row and column control signals are configured, for each transducer element, such that when combined with the

electrical receive signal of that transducer element the electrical receive signal is modified in such a manner as to permit the simultaneous processing of the modified electrical receive signals from said plurality of transducer elements;

a first circuit that combines the modified electrical receive signals of each of said transducer elements to form an array output signal; and

a second circuit coupled to said first circuit that generates image data from said array output signal.

#22
09/628,942

The 1-D system is in large part a subset of the 2-D system and hence, linear scanning, curved linear scanning, and sector scanning may be realized. The teachings herein for the two different implementations of 2-D arrays applies likewise to 1-D arrays.

The 2-D and 1-D scanning systems are now presented in more detail. A general overview of a 2-D system is presented first in which a 1-D array may be substituted with apparent variation, followed by a description of system operation. Discussion of more specific embodiments is then provided, including both (i) achieving ranging in angular scanning and (ii) configuring a 1-D system, amongst other aspects.

Referring to FIG. 1, a perspective view of an acoustic wave imaging system **10** in accordance with the present invention is shown. The system **10** includes interface circuit **20** which is connected via line **85** to operator interface componentry represented by reference numeral **80** and via line **75** to a display mechanism **70**. Both the operator interface componentry **80** and the display mechanism **70** are known in the art and are discussed in more detail below with reference to FIG. 3. The interface circuit **20** is also connected, via line **22**, to a row control circuit **30** and, via line **28**, to a column control circuit **40**. The row and column control circuits **30**,**40** control the phase and frequency of signals propagated to a plurality a M rows and N columns in an array **100** of acoustic transducer elements. Each transducer element comprises a acoustic transducer (cells **110**, **120**,**140**,**170**,**180**,**190** are indicated in FIG. 1) and its corresponding transducer (shown in FIG. 2). The row control signals are propagated over M row control lines or processing channels, represented generally by arrow **35**, and the column control signals are propagated over N column control lines or processing channels, represented generally by arrow **45**.

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Acoustic waves incident on transducers in array **100** cause the generation of a corresponding electrical signal that is combined with the row, X-axis, and column, Y-axis, control signals in each transducer cell and then combined with the output of all other cells before propagation over line **65** to interface circuit **20** in a manner discussed below. In interface circuit **20**, the signal is processed for imaging and output via line **75** to display mechanism **70** for display. The interface circuit **20** is discussed in more detail below with reference to FIG. 3.

Referring to FIG. 2, a schematic/block diagram of array **100** and row and column control circuits **30** and **40**, respectively, is shown (the array is presented as a schematic and the control circuits as block diagrams). The array is comprised of M rows and N columns and a transducer is preferably located proximate the intersection of each row and column signal line. Conventional 1-D arrays often contain 64 or 128 linearly arranged transducers. Accordingly, the array **100** is anticipated to have a size ranging from 64×64 to 128×128 transducers, and thus an approximate size of 100×100 is made reference to herein. In planar and curved planar scanning, discussed below, the array size may be much larger, for example 200×200 to 500×500 or a rectangular combination thereof, of which only a sub-unit is active at any given time. For example, the planar array may be 400×400 transducers, with a subaperture of 100×100 transducers that is active at a given time. If the embodiment of FIG. 2 has 100 row lines and 100 column lines, then 10,000 transducers are supported.

In the composite implementation the transducers are standard electro acoustic transducers. They are processed to a particular size that affords an appropriate center frequency

and bandwidth. In a preferred embodiment, those parameters are respectively 5 MHz and 4 MHz.

FIG. 2 illustrates 9 transducer cells **110** (not labelled in FIG. 2 due to crowding in the figure, but labelled in FIG. 1),**120**,**130**,**140**,**150**,**160**,**170**,**180**,**190** and their corresponding acoustic transducers **125**,**135**,**145**, **155**,**165**,**176**,**185**,**195**. In the composite implementation, each transducer is mounted to its corresponding cell in the same manner that transducers are connected to semiconductor substrates in IR focal plane arrays or the like. The dotted lines are provided to indicate that the number of cells is variable and may be modified in either dimension. Cell **150** is surrounded by a dashed line and will be described as a representative cell.

Cell **150** includes a first mixer **151** for mixing row and column control signals in a manner described below. This mixer is a standard high quality electronic mixer and is preferably doubly balanced. The output of mixer **151** is input to a transmit amplifier (hereinafter referred to as "buffer") **152** which in turn is connected to a transmit and receive (T/R) switch **153**. The T/R switch **153** is controlled by interface circuit **20** (connection not shown, but known in art) and is connected to both the electro-acoustic transducer **155** and an amplifier **157**. When an acoustic wave is received at transducer **155**, a corresponding signal is propagated through T/R switch **153** to amplifier **157**. The output of amplifier **157** is connected to a second mixer **158** which combines the corresponding signal with the output of first mixer **151**. The output of second mixer **158** is connected to the output of the second mixers **128**,**188** from each of the other cells **120**,**180** in the same column via line **102**. The combined second mixer output signals from each column (line **101** provides the combined second mixer signal for mixers **118**,**148**,**178** and line **103** provides the combined second mixer signal from mixers **138**,**168**,**198**) are connected at point **199** and transmitted to interface circuit **20** (FIG. 1) on signal line **65**.

The components of cell **150** are provided in the other cells and are identified therein by both a similar geometric symbol and reference numerals that use the same number in the units digit. For example, the first mixer **151** of cell **150** is identified as **111** in cell **110**, **121** in cell **120**, etc. It should be noted that although a buffer, a T/R switch and an amplifier are provided in each cell to improve signal characteristics, their use is not required to achieve the mathematical signal processing described herein.

The row control circuit **30** consists of a plurality of individual row signal generating circuits **231**. A first of these $\boxed{\text{in}}$ connected via line **251** to the first mixer of cells **110**,**120**, **130**. Similarly, a second and a last row signal generating circuit **231** are connected via lines **252** and **253** to cells **140**,**150**,**160** and cells **170**,**180**,**190**, respectively. The column control circuit **40** consists of a plurality of individual column signal generating circuits **241**. A first of these $\boxed{\text{in}}$ connected via line **261** to the first mixer of cells **110**,**140**, **170**. A second and a last column signal generating circuit **241** are connected via lines **262** and **263** to cells **120**,**150**,**180** and cells **130**,**160**,**190**, respectively.

The row and column control are connected to the system control circuitry **300** (of FIG. 3) and provide frequency and phase modified signals in accordance with equations below, e.g., chirps on transmit, continuous waves during receive, and multiple component large bandwidth signals for sector scanning range focusing. In one embodiment, the row and column control circuits **30**, **40** include frequency generators and phase shifters which are generally known in art and which receive initial values and control signals from inter-

characteristic thereof, e.g., frequency or phase, results in a change in time delay at a matched output therefor. One suitable coded signal is a linear FM chirp, which is taught herein in conjunction with a matched filter.

Referring to FIG. 4, a frequency versus time diagram is shown for a linear FM chirp. Chirps as a characterized electrical signal and matched filters therefor are generally known. Though an up chirp is shown it should be recognized that since the attenuation of sound is strongly dependent on frequency, a down chirp may also be used and may be more appropriate in some instances. Furthermore, it may also be appropriate to transmit high frequencies at a higher voltage level.

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For imaging purposes, a chirp must be converted into a pulse before detection and display. This is accomplished by way of the matched filter **320**. A matched filter is a filter whose frequency response is the complex conjugate of the frequency spectrum of a signal to be "matched." By shifting the frequency of the incoming linear FM chirp, the output pulse of the matched filter will vary in the time that it exits filter **320** (and **720** at FIG. **11**). This delay, is directly proportional to the shift of the chirp signal away from its original center frequency. Thus, with an appropriately designed matched filter, variable time delays can be implemented via frequency shifts.

Using chirps (or other suitable coded signals), the frequency of every row and column signal is chosen such that the resulting shift in frequency will give rise to the appropriate time delay once the chirp is compressed into a pulse by a matched filter.

Composite and Non-Linear Implementations

The array **100** has at least two implementations. A first is the composite implementation where essentially all the components of each cell are fabricated in semiconductor material and the electro-acoustic transducer is connected thereto. A second implementation involves selecting an appropriate non-linear electro-acoustic, non-linear dielectric material (discussed immediately below) that performs the necessary mixing functions of one or both of the first and second mixers as a characteristic property thereof. With respect to the depiction of array **100** in FIG. **2**, it should be recognized that the symbols for the first and second mixers represent, in the first implementation, physical mixers, and in the second implementation, functions that are being performed by the non-linear electro-acoustic, non-linear dielectric material. In addition, in the second implementation, the other electronic components, i.e., the buffer, T/R switch and amplifiers are not provided in the physical array, but amplifiers and the like are provided off board.

One reason for pursuing the non-linear implementation is that it is more cost effective. The quadratic relationship of the applied voltage to mechanical strain of an electrostrictive transducer can be used to mix the row and column control signals. Such an array can be constructed with rows of electrodes connected to one face of all the transducers and columns of electrodes connected to the other face (i.e., back). In a preferred embodiment, the non-linear electro-acoustic, non-linear dielectric material is electrostrictive with a dielectric constant that changes with applied electric field. Furthermore, barium strontium titanate is preferred.

In operation, the voltage at each array element will be the sum of the signal on its face and back. The resulting strain will be the square of this sum. With the appropriate choice of front and back control signal frequencies (row and column), only the sum (or difference) frequency and phase component will fall within the pass band of the transducer and be radiated.

Electrostrictive transducers can also be used in receive providing that the transducer material has a large non-linear dielectric response as well as a large electrostrictive response. The required row and column mixing is performed by the non-linear dielectric response. In other words, an electric field is produced that is, for example, the square or some other non-linear response of the electric field across the transducer due to the non-linear dielectric response of the transducer material. In receive, the effect of electrostriction is to change the dielectric constant (permittivity) of the transducer as a function of mechanical stress resulting from the incoming acoustic field. Parametric mixing takes place between the electric and acoustic fields to produce an electro-acoustic signal. This produces a number of frequency components (at least 4) only one of which will be the desired signal. Through a suitable choice of materials and control frequencies such operation can. create the desired 2-D focus of acoustic energy.

Referring now to the composite implementation, this implementation provides several advantages, mostly stemming from its manufacture in semiconductor material that permits the incorporation of a large range of electronic circuits. Some of the advantages of the composite implementation are discussed herein. Also included is the possibility to integrate the row and column control circuits **30**,**40** on the array chip. Such integration would reduce the number of array connections from several hundred to a few dozen and significantly reduce the cost of the system. Integrating the array and the control circuits on a single chip also permits manufacture of a portable imaging system low enough in cost to be used in essentially all situations where volummetric and/or real time 2-D imaging are required.

OPERATION

All phased array imaging systems image by electronically synthesizing a lens. For 3-D imaging, one needs to synthesize a 2-D lens. In this case, the requisite delay over the aperture can be separated into two components, one that depends only on X and one that depends only on Y as taught herein.

For apertures that are less than one half the focal length (this is the normal operating condition for medical imaging), the lens equation can be approximated by a function that is separable into independent X and Y components. As seen in Equation 1, this is the classical paraxial approximation; an approximation that is the foundation for Fourier Optics as well as other field in wave mechanics.

$$\Delta(X,Y)=(X^2/(2*R)+Y^2/(2*R))/V \qquad \text{Eq. 1}$$

The paraxial approximation allows one to decompose a 2-D lens into two, orthogonal, 1-D lenses, one immediately in front of the other. At each point on the aperture, the phase delay from one lens adds to that of the other to produce the same phase delay as would result from a single 2-D lens. This means that a 2-D array can be used to synthesize a 2-D lens by phasing the rows with a phase relationship that will create a 1-D focus in the X-axis and the columns with one that will create a 1-D focus in the Y-axis. Such phasing is now discussed in more detail, first in a general continuous wave context and then in a context for broadband operation using coded signals.

In general operation, the row signals are used to produce a 1-D focus in the X direction while the columns signals are used to produce a 1-D focus along the Y axis. To achieve the desired 2-D focus, the row and column signals are combined in a manner such as that achieved by mixing (or multiplying)

significantly outside of this band. It should be recognized that this chirp component lasts much longer in time than the desired transmitted signal as well as covering a frequency range longer than the response of the transducer. The bandwidth of the transducer and the chirp rate is chosen such that the acoustic chirp transmitted from the element will be the desired length.

Referring to Equation 2, the relative timing of the transmit control signal at some array element is determined by the relative time of transit from a specific array element (a particular row-column, X-Y location) and the desired focal point (X,Y,θ,Φ,R). X and Y are the spatial location of the element. θ and Φ are the azimuth and elevation direction cosines of the ray connecting the center of the array to the focal point, and R is the range from the center of the array to the focal point. Using the paraxial approximation this simplifies to Equation 3.

Separating Equation 3 into X and Y components produces the row and column control signals, Equations 4 and 5 respectively, for transmit. In these equations, ωr and ωc are the row and column base frequencies, α is the chirp rate and V is the velocity of sound.

$$\Delta(X,Y)=\mathrm{sqrt}(R^2+X^2+Y^2-2XR\theta-2YR\Phi)/V-R/V \qquad \text{Eq. 2}$$

$$\begin{aligned}\Delta(X,Y) &\cong (X^2/2R + Y^2/2R - X\theta - Y\phi)/V \qquad \text{Eq. 3}\\ &\cong \Delta(X)+\Delta(Y)\end{aligned}$$

$$Sr(X)=\cos(\omega r^*(t-\Delta(X))+\alpha^*t^2/2-2\alpha^*\Delta(X)^*t+\alpha^*\Delta(X)^2) \qquad \text{Eq. 4}$$

$$Sc(Y)=\cos(\omega c^*(t-\Delta(Y))+\alpha^*t^2/2-2\alpha^*\Delta(Y)^*t+\alpha^*\Delta(Y)^2) \qquad \text{Eq. 5}$$

In receive, the purpose of the control signals which have the characteristics of continuous wave signals, is to shift the frequency and phase of each signal so that, as that signal occurs, it coherently adds with all the other signals as they progress in their time sequence. The net result is, for a single point source, a single output chirp whose length in time and frequency corresponds to the total time over which the acoustic energy is insonifing the array aperture. For a point source located at a large angle away from array **100**, the resulting output chirp can last over 20 microseconds even though the chirp coming from the point source or target lasted only 10 microseconds.

Mathematically, this requirement to achieve coherence can be established by changing the phase and amplitude of every chirp so that the summed output produces a single chirp centered in time with the chirp signal arriving at the center element of the array. Equation 6 provides the condition for coherence (ωa is the base frequency of the received chirp). Solving for the frequency shift 'ωs*t', and the phase shift 'ψ', gives the frequency and phase shift for each array element to ensure a coherent sum, Equation 7. Separating this equation into its row and column components gives rise to the row and column control signals, Equations 8 and 9 respectively, for receive (ωlor and ωloc are the rows and column local oscillator frequencies and tz is the transit time from the center of the array **100** to the target).

$$\cos(\omega a^*(t-tz)+\alpha^*(t-tz)^2)=\cos(\omega\Delta^*(t-\Delta(X,Y))+\alpha^*(t-\Delta(X,Y))^2+\omega s^*t+\psi) \qquad \text{Eq. 6}$$

$$\omega s=2^*\alpha^*\Delta(X,Y)$$

$$\psi=\omega a^*\Delta(X,Y)-\alpha^*(\Delta(X,Y))^2 \qquad \text{Eq. 7}$$

$$Sr=\cos(\omega lor^*t+2^*\alpha^*\Delta(X)^*t+\omega a^*\Delta(X)-\alpha^*(\Delta(X)^2)) \qquad \text{Eq. 8}$$

$$Sc=\cos(\omega loc^*t+2^*\alpha^*\Delta(Y)^*t+\omega a^*\Delta(Y)-\alpha^*(\Delta(Y)^2)) \qquad \text{Eq. 9}$$

column control signals. This is why the non-linear array is not effective at large angles.

Referring to FIG. 7, a schematic diagram of two transducer cells with phase adjustment for angular scanning in accordance with present invention is shown. The two cells **610** and **640** are analogous to cells **110** and **140**, for example, of FIG. **2**.

Referring to cell **610**, the first mixer **611**, buffer **612**, T/R switch **613**, amplifier **617** and second mixer **618** are analogous to their counterparts in cell **110**. Cells **610**, **640** each include a phase shifter **614**, **644** and a voltage divider **616**, **646**. A DC signal source **605** for generating a common DC control signal is connected to the voltage divider. It is controlled by an additional processing channel (not shown).

The limitations imposed by Eq. 15 are removed by the addition of the phase shifters **614**, **644** as programmed by the voltage divider outputs. The voltage dividers **616**, **646** essentially comprise two resistors that can be precisely selected to divide the common DC signal to a unique voltage level. This voltage level or ratio of input to output voltage is chosen for each cell to be proportional to its XY position in the array (**100** of FIG. **2**). Eq. 16 shows the relationship of the DC control signal and Eq. 17 shows the actual phase shift introduced by each phase shifter in array **100** (FIG. **2**), represented in FIG. **7** by phase shifters **614** and **644**.

$$Scorr=(\theta*\Phi)*(\omega n+2*a*R/V)/(2*R*V) \qquad \text{Eq. 16}$$

$$C=X*Y*Scorr \qquad \text{Eq. 17}$$

The immediately preceding discussion illustrated a way of achieving unique phase correction for each transducer for achieving angular scan in transmit. A way of angularly focusing in receive is now discussed.

Prior art acoustic imaging systems sample the output image at discrete ranges. For this reason, a continuous output, in range, is not required. One can use a sequence of range outputs, in other words, discontinuous or discrete dynamic focusing, without any loss in image quality that is detectable by the human eye.

In the composite implementation, discrete focusing is achieved by at least the two following approaches or a combination thereof. A first approach is to use as many processing electronic cells per transducer as the number of range increments desired. The control signals only have to be in existence for the duration over which the energy from a particular range point insonifies the array. This concept is illustrated in FIG. **8**, wherein dashed line **681** represents a ray or line emanating from the center of array **100** on which range points for focusing lie. The ray **681** is defined by certain elevation and azimuth angles. Segment **683** represents one process period which is essentially the time over which energy from a focused range point insonifies the array. The range focus along ray **681** is sequential extended a distance equal to the speed of sound in the relevant medium times the period of insonification, up to a distance that is no longer practical or desirable for scanning. For a practical design for use in medical ultrasound imaging, the process period is on the order of 20 microseconds. This means that every 20 microseconds, the control signals can change to focus on a new range point. Having 40 processing cells for every array element would permit one range sample every 0.5 microseconds; approximately what is used for current imaging systems when displaying 16 cm of range.

A second approach to obtain multiple range samples is to use the high electronic bandwiths of current integrated electronic circuits. Assuming a bandwidth requirement of 10 MHz per range channel, a 400 MHz electronic bandwidth

would permit 40 simultaneous range channels. Implementation of this approach in the imaging system **10** described herein is now presented.

Referring to FIG. **9**, a range versus frequency band diagram for implementing discrete focusing is shown. A plurality of range points are defined, point **1**, point **2**, . . . point j, that sufficiently approximate the range overwhich focusing is desired along a particular ray (**681** of FIG. **8**). A specific frequency band, band **1**, band **2**, . . . band j, is defined for each range point.

Referring to FIG. **10**, a phase accumulator **691** is provided either in or in communication with the interface circuit **20**. The phase accumulator **691** preferably receives a digital signal, v(t), from signal generating circuitry (not shown, but generally known), in system control circuitry that includes components for each of the j frequency bands of FIG. **9**. Thus,

$$v(t)=v(t)_1'+v(t)_2'+ \ldots +v(t)_j' \qquad \text{Eq. 19}$$

where $\omega lor_1+\omega loc_1$=band $v(t)_1$ center frequency and $\omega lor_2+\omega loc_2$=band $v(t)_2$ center frequency, etc.

The phase accumulator **691** preferably includes a digital to analog converter (not shown) or one is placed downstream thereof. The output of accumulator **691** is the Scorr signal which is delivered to the voltage dividers (**616**,**646** of FIG. **7**). The output of each voltage divider is the control signal, C, which is propagated to the phase shifters (**614**, **644** of FIG. **7**) to uniquely code the receive focusing signal for each cell. In the exemplary embodiment, mentioned immediately above, each band or frequency component $v(t)'$ differs by 10 MHz from the adjacent band. Thus, for 40 range channels, v(t) has a band width of 40×10 MHz=400 MHz.

Referring to FIG. **11**, a modification in the interface circuit **20** to appropriately process a multi frequency component signal in accordance with the present invention is shown.

In contrast to the singular receive channel **305** of the embodiment of FIG. **3**, the embodiment of FIG. **11** includes j receive channels **705** (**705**$_1$, **705**$_2$, **705**$_j$) which contain matched filters **720**$_1$, **720**$_2$, **720**$_j$ that are specifically configured for their corresponding frequency component $v(t)_1'$, $v(t)_2'$, $v(t)_j'$, respectively. Continuing with the current example of 40 range points and 40 frequency components, there are 40 receive channels **705** in the modification to the interface circuit **20** illustrated in FIG. **11**. It should be recognized that one can combine multiple cells per transducer, for example 6 cells per transducer (with appropriate frequency multiplexing and phase shifting as taught herein), with larger bandwidth signals, for example 6 frequencies in the bandwidth and 6 receive channels, to achieve the desired number of range samples, in this example, 6×6=36.

1-D Implementation and Annular Array

Referring to FIG. **12**, a 1-D array **800** for an acoustic scanning system in accordance with the present invention is shown. The array **800** is integrated into the system **10** of FIG. **1**, replacing array **100**. Since array **800** is one dimensional, control lines are only implemented in one dimension, either row or column control. The row control circuiting **30** is shown in FIG. **12** and hence in integrating array **800** into system **10**, the column circuit **40** and related electronics are removed. Each cell **810**,**840**,**870** does not contain a first mixer, such as mixer **111** and the like of FIG. **2** because of the absence of column control lines, but does include a buffer **812**,**842**,**872**, a T/R switch **813**,**843**, **873** receive amplifier **817**,**847**,**877** and a second mixer **818**, **848**,**878**. Each cell is connected to a transducer **815**,**845**,

electrical receive signal modifies the frequency and phase of that electrical receive signal in such a manner as to permit the coherent combination of the modified electrical receive signals from all of said plurality of transducer elements;

means for combining the electrical receive control signal of each transducer element with an electrical receive signal generated by that transducer;

means coupled to each of said transducer elements for combining the modified electrical receive signals from said transducer elements so as to form a coherently combined array output signal;

means coupled to said transducer output combining means for decoding a combined reflected coded signal in the coherently combined array output signal to produce a decoding means output signal; and means coupled to said decoding means for generating image data from said decoding means output signal.

2. The apparatus of claim 1, wherein ~~said coded signal~~ is a chirp.

3. The apparatus of claim 2, wherein said decoding means comprises at least one matched filter for coded signal decoding.

4. The apparatus of claim 1, wherein said chirp is a linear FM chirp.

5. The apparatus of claim 1, wherein said array has a size of M rows and N columns and said electrical transmit control signal generating means comprises means for generating individual row and column transmit control signals for each of said rows and columns, the electrical transmit control signal for each transducer element being a combination of the transmit row and column control signals for that transducer.

6. The apparatus of claim 5, wherein at least one of said row and column transmit control signals for a given transducer element contains a frequency based coded signal.

7. The apparatus of claim 5, wherein said electrical receive control signal generating means comprises means for generating individual row and column receive control signals for each of said rows and columns, the electrical receive control signal for each transducer being a combination of the receive row and column control signals for that transducer.

8. The apparatus of claim 1, wherein said coded signal includes a frequency based code.

9. The apparatus of claim 1, wherein said array is a one dimensional array with a plurality of rows and one column.

10. The apparatus of claim 1, wherein said array of transducer elements comprises M rows and N columns, where M and N are positive integers and at least one of M and N is greater than 1;

at least one of said transmit control signal generating means and said receive control signal generating means includes means for generating row and column control signal components; and

wherein each transducer element includes an active electronic device for combining said row and column control signal components for that transducer element.

11. The apparatus of claim 1, wherein each transducer element includes a transducer comprised of a non-linear electro-acoustic, non-linear dielectric material.

12. An acoustic imaging apparatus, comprising: a plurality of electro-acoustic transducer elements arranged in an array, each capable of transmitting an acoustic signal and generating an electrical signal representative of an incident acoustic wave;

control means having a plurality of control channels coupled to each of said plurality of transducer

wherein

begin new paragraph

Claim 12, line 1, after "comprising:" please begin a

elements, said control channels being fewer in number than said transducer elements;

wherein said control means generates control signals for each transducer element that when combined with the electrical receive signal of that transducer element modifies the electrical receive signal in such a manner as to permit the simultaneous processing of the modified electrical receive signals from said plurality of transducer elements;

means for combining the modified electrical receive signals of each of said transducer elements to form an array output signal; and

means coupled to said combining means for generating image data from said array output signal.

13. The apparatus of claim 12, wherein said array has a plurality of rows and a plurality of columns each having one of said plurality of control channels associated therewith, insert semi-colon

said control signal generating means further including means for generating row and column control signal components; and

wherein each transducer element is uniquely and simultaneously controlled by a combination of the row and column control signal components for that transducer element.

14. The apparatus of claim 12, wherein said control signal generating means further includes means for generating a transmit control signal for each transducer element that contains a frequency based coded signal for transmission by each transducer element.

15. The apparatus of claim 14.

further comprising means for decoding a reflected frequency based coded signal.

16. An acoustic imaging system, comprising:

an array of electro-acoustic transducer elements having M rows and N columns, where M and N are positive integers and at least one of M and N is greater than one;

M row control lines, each coupled to the transducer elements in one of said M rows;

N column control lines, each coupled to the transducer elements in one of said N columns;

control means coupled to each of said M row and N column control lines for generating row control signals for each of said row control lines and column control signals for each of said column control lines, a control signal for each transducer being a combination of one of said row control signals and one of said column control signals;

a plurality of active devices, each coupled to one of said transducer elements for combining the row control signal and the column control signal of that transducer element;

means for combining the output of each transducer element to produce an array output signal; and

means coupled to said transducer output combining means for generating image data from said array output signal.

17. The apparatus of claim 16, wherein said active device is an active electronic device.

18. The apparatus of claim 17, wherein said control means includes means for generating a transmit control signal that contains a frequency based coded signal for each transducer element; and

wherein said apparatus further comprises means in communication with each of said transducer elements for

modifying a reflected coded signal received thereby to achieve a delay encoded in the coded signal, said delay for each transducer element being based on the relative position of that transducer element in the array.

19. The apparatus of claim 16, wherein said active device includes a non-linear electro-acoustic material.

20. The apparatus of claim 16, wherein said active device includes a non-linear electro-acoustic material for combining row and column control signal on transmit and an active electronic device for combining row and column control signal on receive.

21. The apparatus of claim 16, wherein said active device includes a non-linear electro-acoustic, nonlinear dielectric material.

22. A method for acoustic imaging, comprising the steps of:

providing control logic;

providing a plurality of transducer elements arranged in an array, each coupled to said control logic and capable of transmitting an acoustic signal representative of an electrical transmit control signal propagated from said control logic and generating an electrical receive signal representative of an incident acoustic signal;

generating an electrical transmit control signal for each transducer element such that the electrical transmit control signal for each transducer element contains a coded signal;

generating an electrical receive control signal for each transducer element that contains an appropriate frequency and phase shift that when combined with that transducer element's electrical receive signal permits the coherent combination of the electrical receive signals of each of the plurality of transducer elements;

combining the coherent output signals from said transducer elements so as to form a coherently combined array output signal;

decoding a combined reflected coded signal in the coherently combined array output signal to produce a decoded output signal; and

generating image data from the decoded output signal.

23. An acoustic imaging apparatus, comprising:

control logic;

a plurality of transducer elements arranged in an array, each coupled to said control logic and capable of transmitting an acoustic signal representative of an electrical transmit control signal propagated from said control logic and generating an electrical receive signal representative of an incident acoustic signal;

means within said control logic for generating an electrical transmit control signal for each transducer element that contains a frequency based coded signal and [cause] causing each transducer to emit an acoustic signal representative of said coded signal;

means for modifying the frequency and [chase] phase of an electrical receive signal of each transducer element for coherently combining reflected coded signals within the electrical receive signals thereof;

means coupled to said modifying means for decoding the combined reflected coded signal to achieve a time delay based on that coded signal; and

means coupled to said decoding means for generating image data from an output signal therefrom.

add following claims